



Status of the Combined-Cycle Engine Large-Scale Inlet Mode Transition Experiment

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The Large-Scale Inlet Mode Transition (LIMX) experiment is currently being conducted in the 10x10 foot supersonic wind tunnel at the NASA Glenn Research Center. The experiment has involved the efforts of a team for over four years to get to the first phase of testing, which is examining the aerodynamic characteristics of the inlet. The LIMX inlet involves dual flowpaths: one to provide flow to a turbine engine and one to provide flow to a dual-mode ramjet/scramjet. A rotating splitter cowl can close off the turbine flowpath, which would occur as the propulsion system transitions from turbine power to ramjet/scramjet power at Mach 4. The first phase of the experiment will simulate the turbine and ramjet/scramjet flows using cold pipes with flow rates controlled by mass-flow plugs. Much of the testing will characterize the performance of the turbine flowpath (total pressure recovery and distortion at the engine face location) as factors such as bleed rates and configuration and vortex generators are varied during the inlet mode transition. The performance of the inlet will also be examined at off-design Mach numbers (2.5-3.0) and at angle-of-attack.



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Hypersonics Project

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Introduction

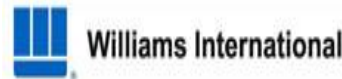


- CCE - Combined-Cycle Engine
- LIMX - Large-Scale Inlet Mode Transition (10x10 ft wind tunnel scale)
- IMX - Small-Scale Inlet Mode Transition (1x1 ft wind tunnel scale)

Outline

- Background
- Physical description of the LIMX model
- Plans, objectives, and goals of the LIMX experiment
- Results from the IMX test and pre-test CFD analyses
- Summary

LIMX Team

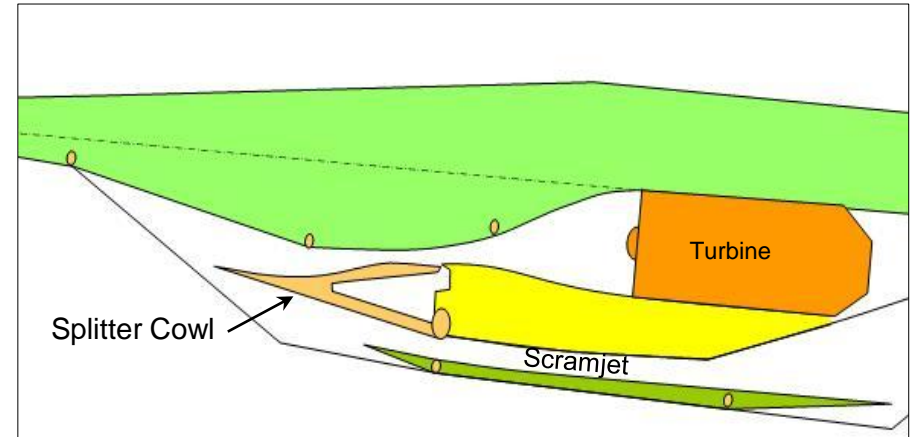


LIMX Test Objectives and Plans



Test Objectives

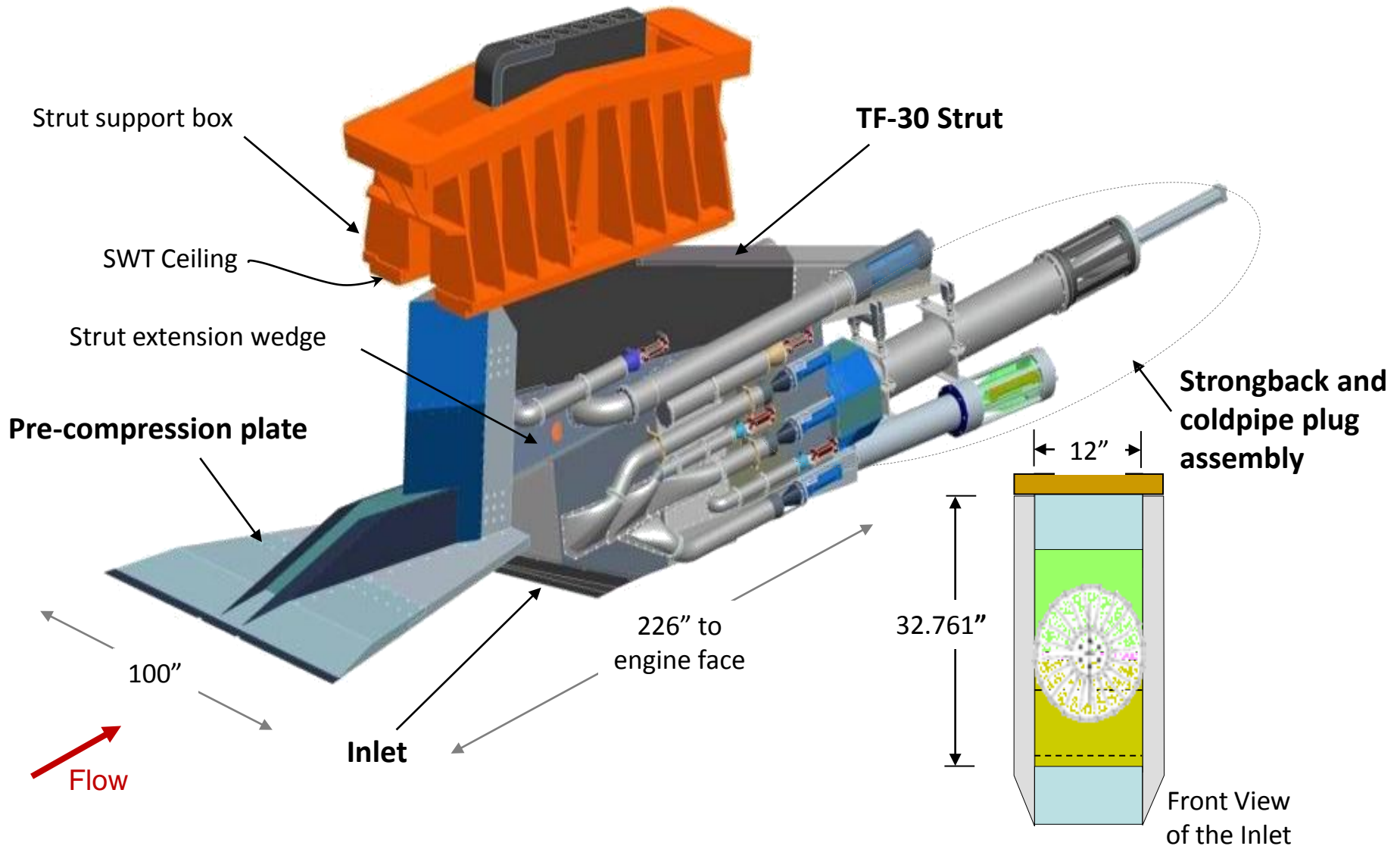
- Demonstrate inlet mode transition at Mach 4.0.
- Evaluate the inlet performance during inlet mode transition at Mach 4.0.
- Develop control schemes for stable inlet mode transition.
- Validate CFD tools.
- Characterize the total pressure distortion at the turbine fan face through inlet mode transition.
- Develop realistic distortion characteristics throughout the inlet mode transition Mach number range.
- Evaluate operability due to disturbance in angle-of-attack and Mach number.
- Demonstrate inlet mode transition at Mach 3.0
- Evaluate off-design performance at Mach numbers between 2.0 and 3.5.



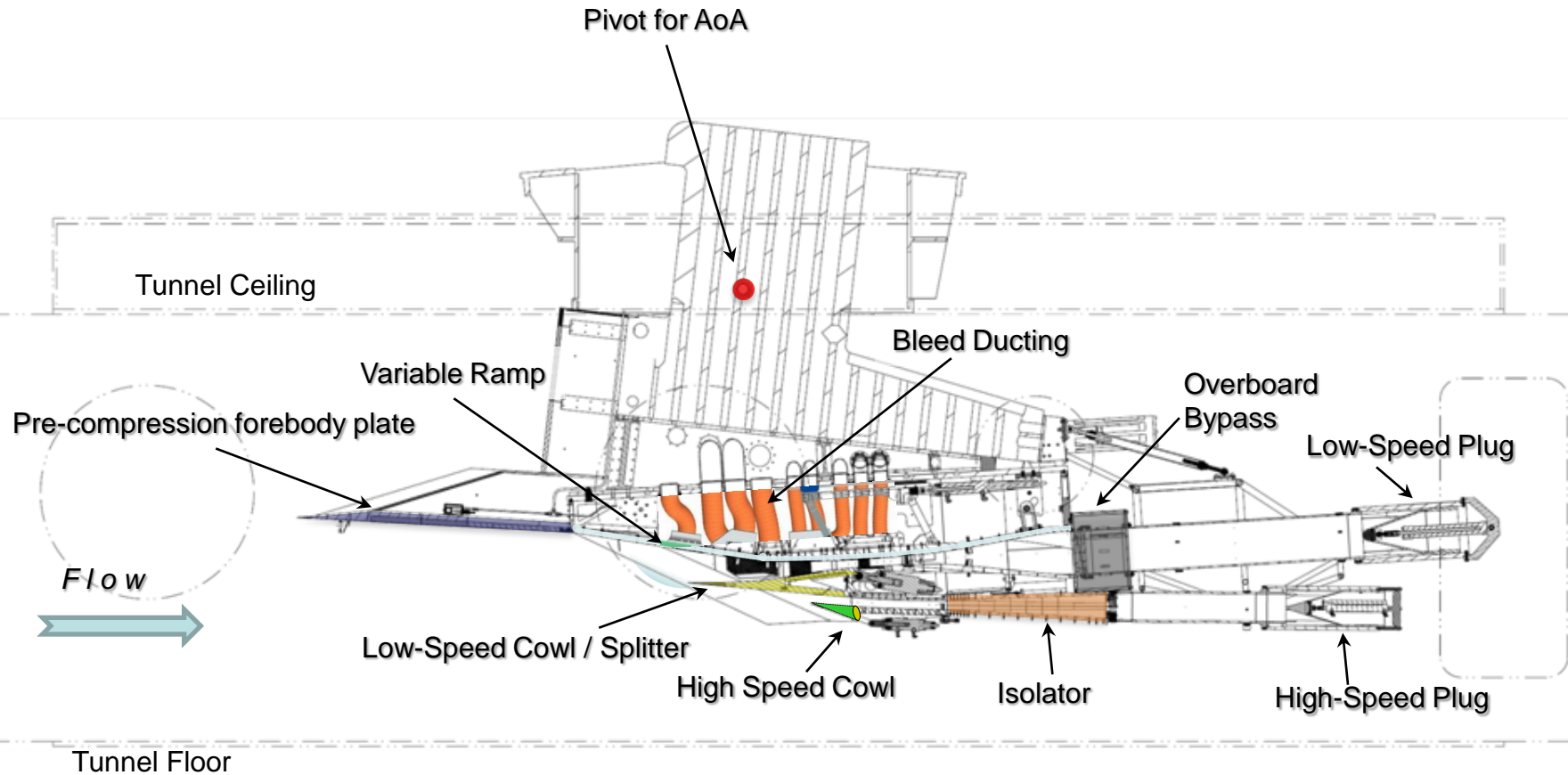
Test Approach - 4 Phases

1. Inlet mode transition, performance, and operability characterization (March – May 2011).
2. System Identification of inlet dynamics for controls (June – August 2011).
3. Demonstrate control strategies for smooth & stable mode transition without inlet unstart (2012).
4. Add turbine engine/ nozzle for integrated system test (2013).

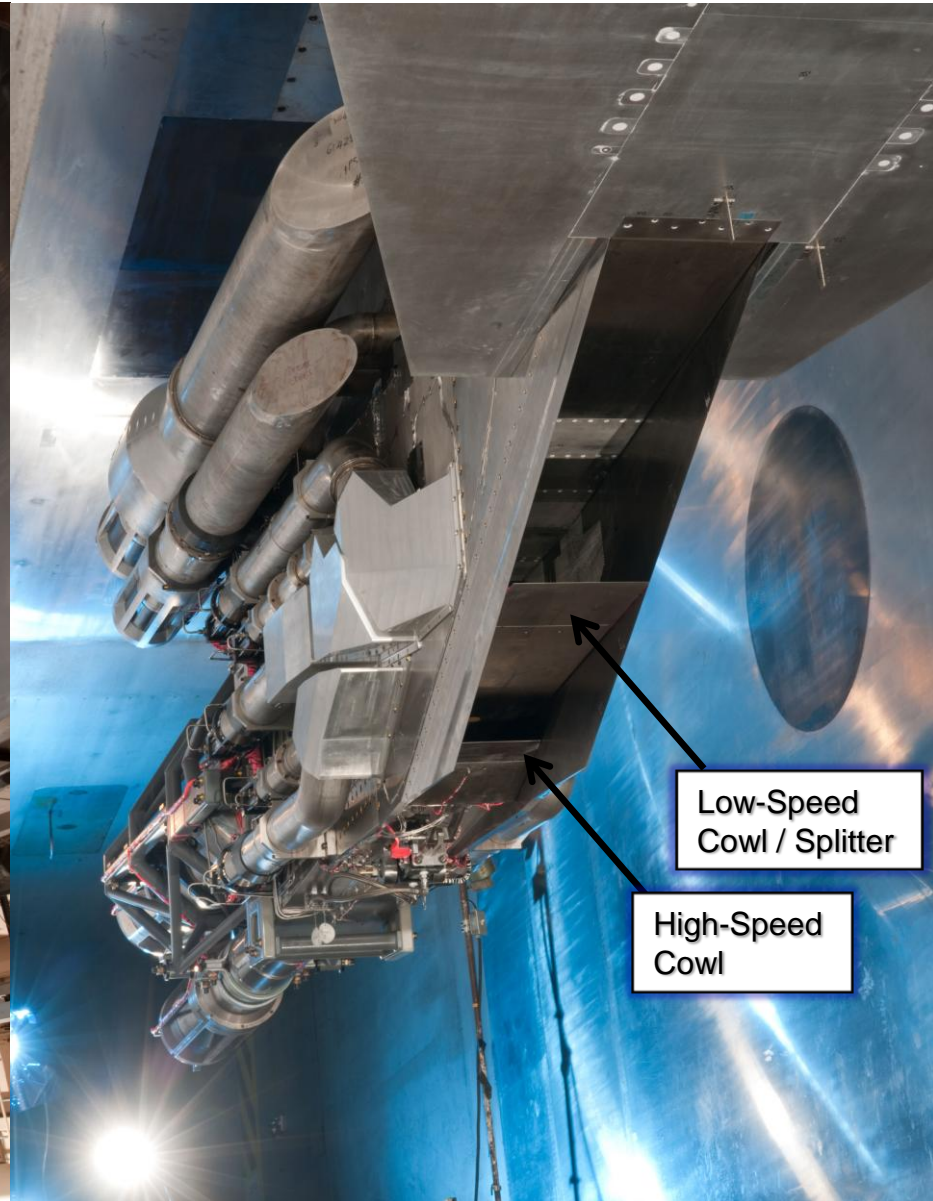
LIMX Model Overview



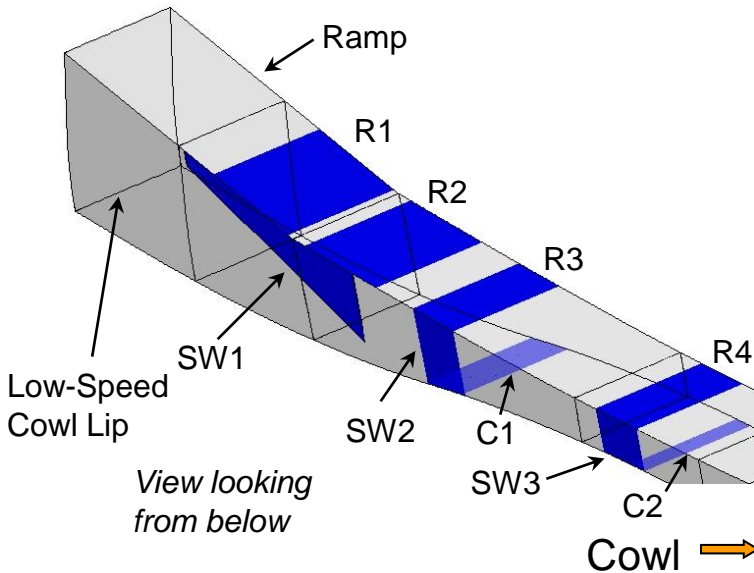
LIMX Model Features



LIMX Installed in the 10x10 SWT

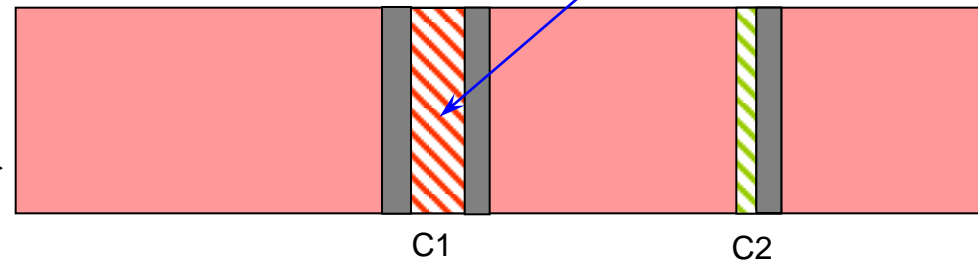


Bleed Regions for the Turbine Flowpath

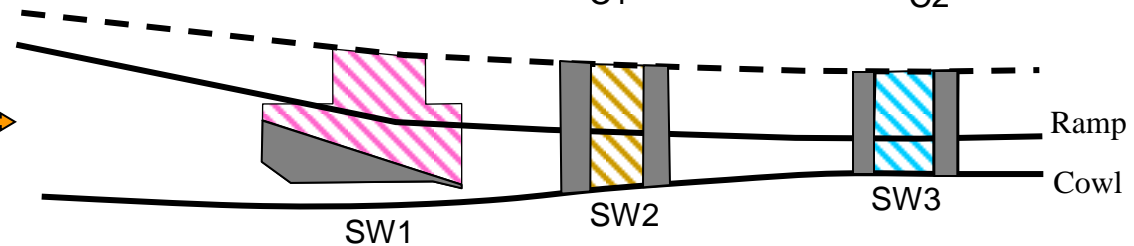


Bleed configuration "A7" shown

Bleed airflow is removed from the inlet duct through porous surfaces. Airflow removed from each bleed region is compartmented and separately controlled.

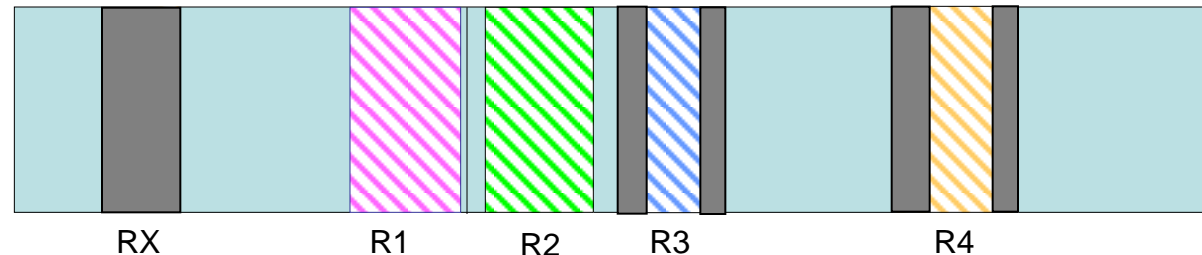


Sidewall →



Expect total bleed less than 15% (Goal is 10%)

Ramp →

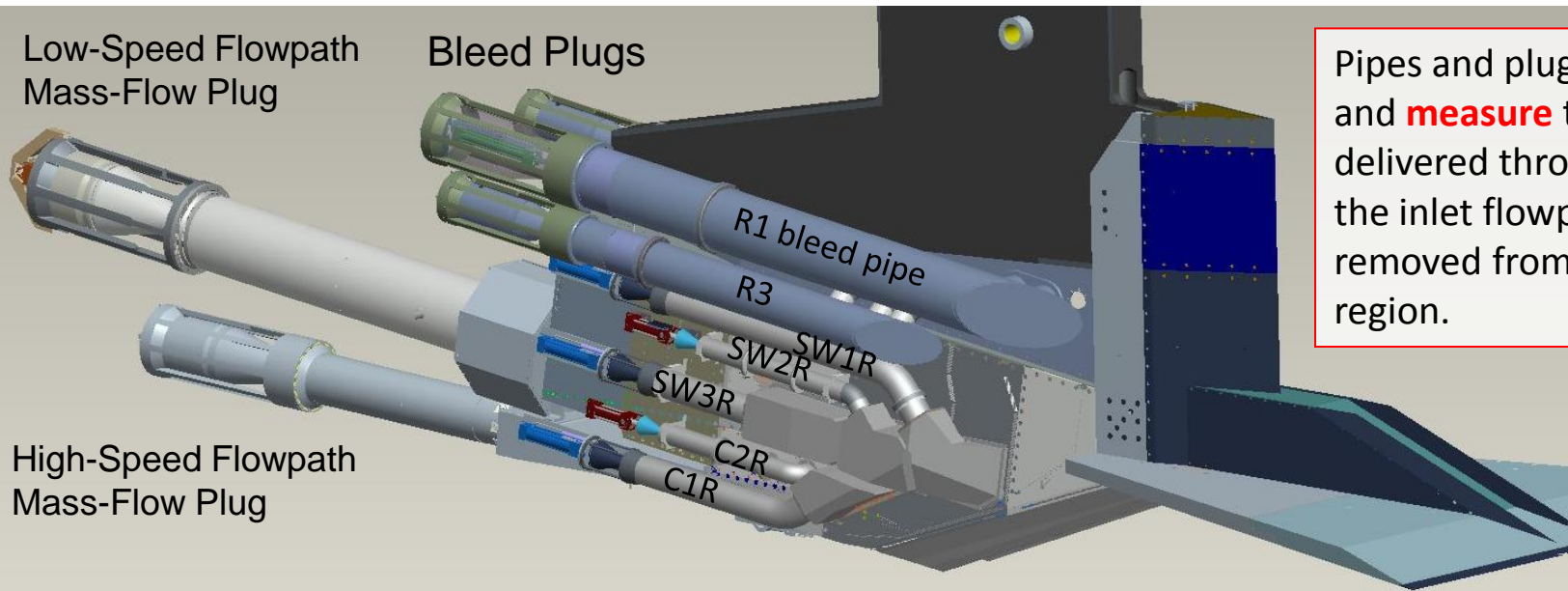




Bleed Pipe and Mass Flow Plug Locations

Low-Speed Flowpath
Mass-Flow Plug

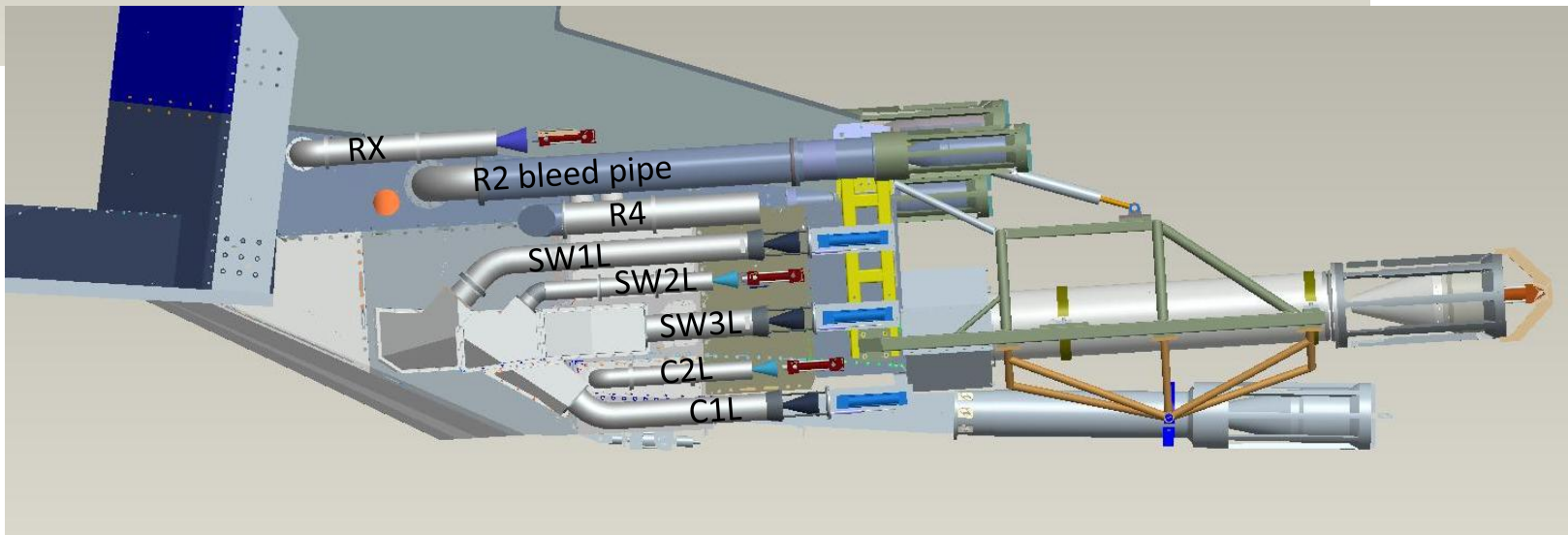
Bleed Plugs



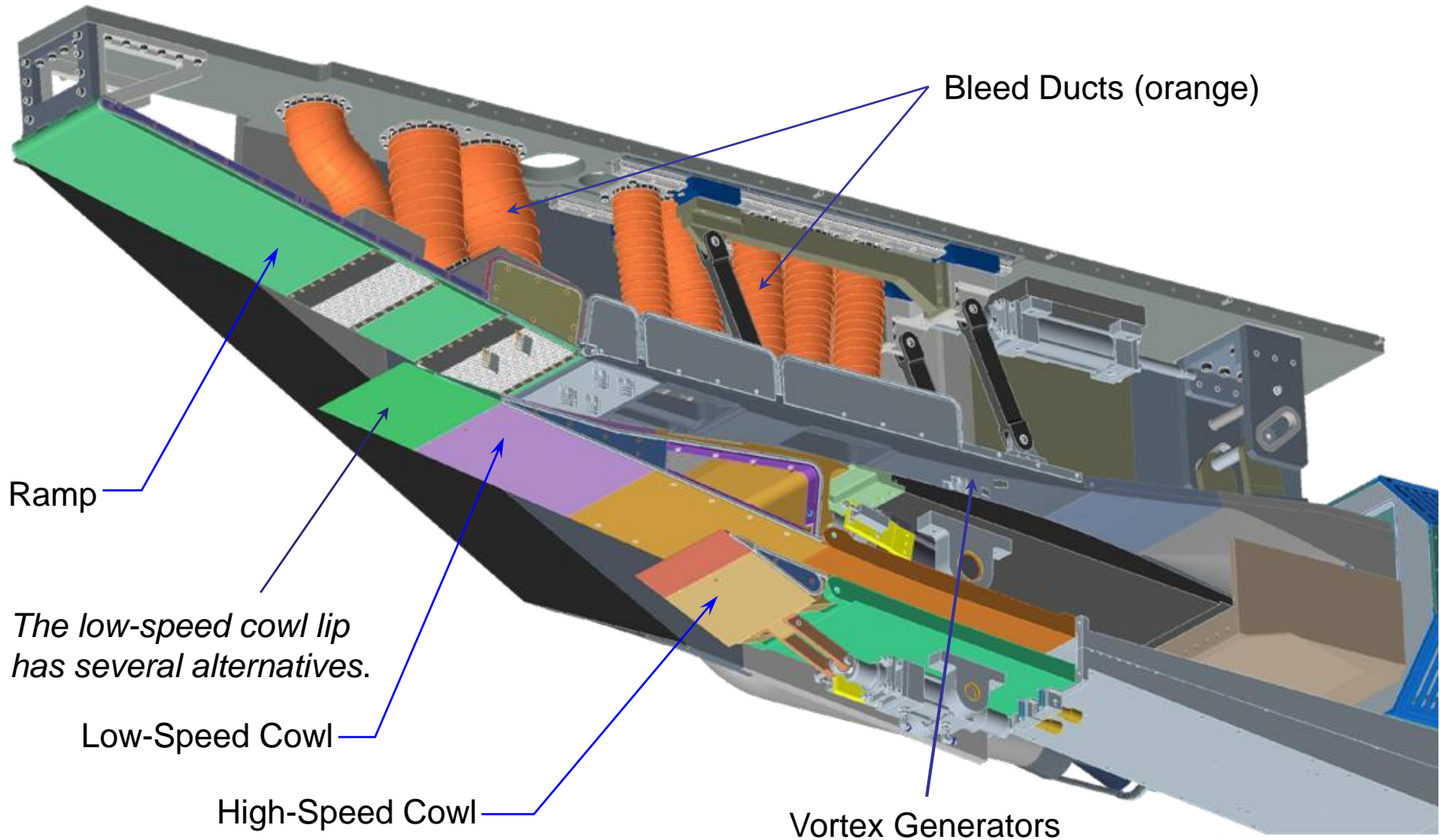
Pipes and plugs **control** and **measure** the airflow delivered through each of the inlet flowpaths and removed from each bleed region.

High-Speed Flowpath
Mass-Flow Plug

*Bleed
rates can
be varied.*

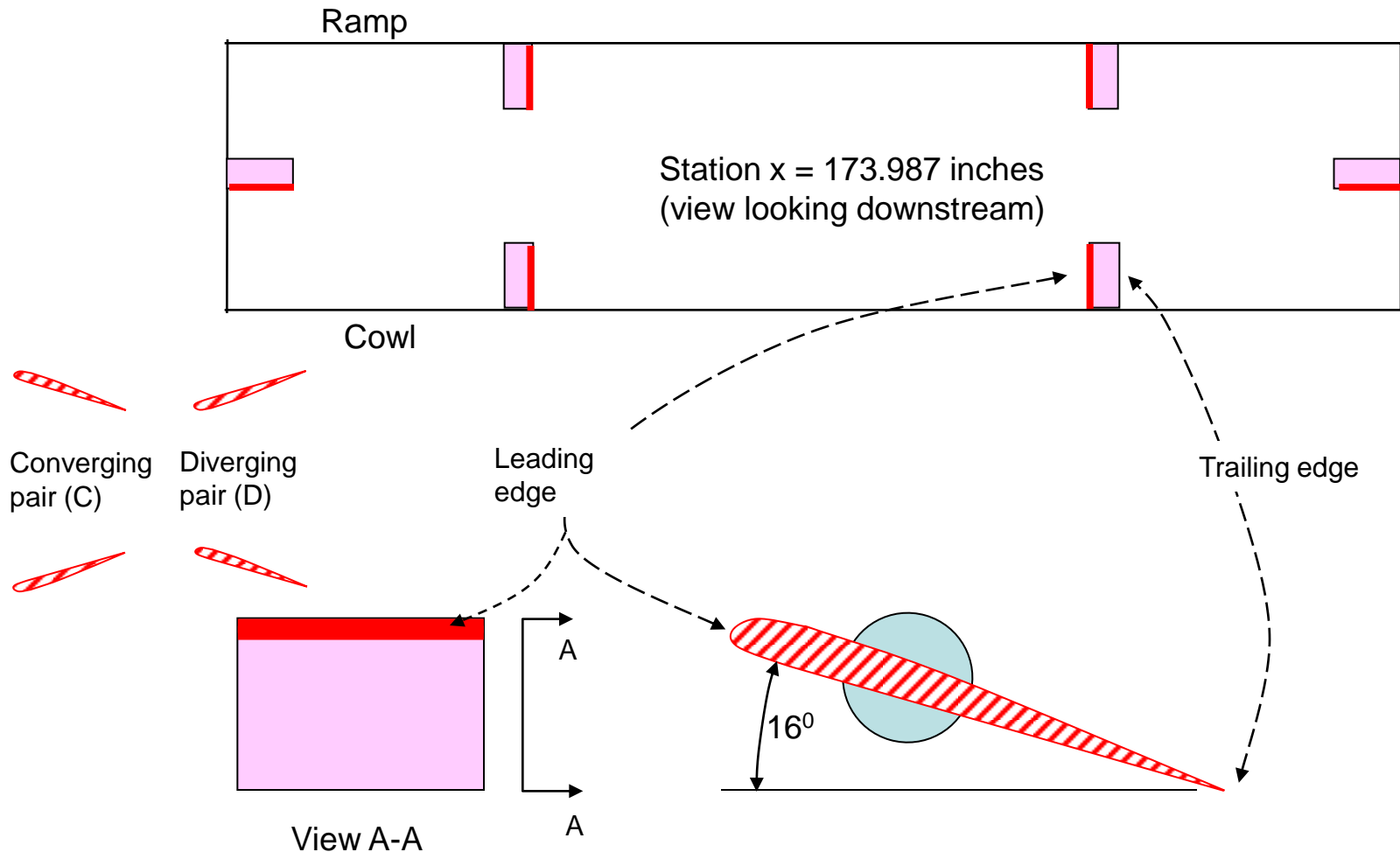


Variable Geometry Systems and Bleed Ducting



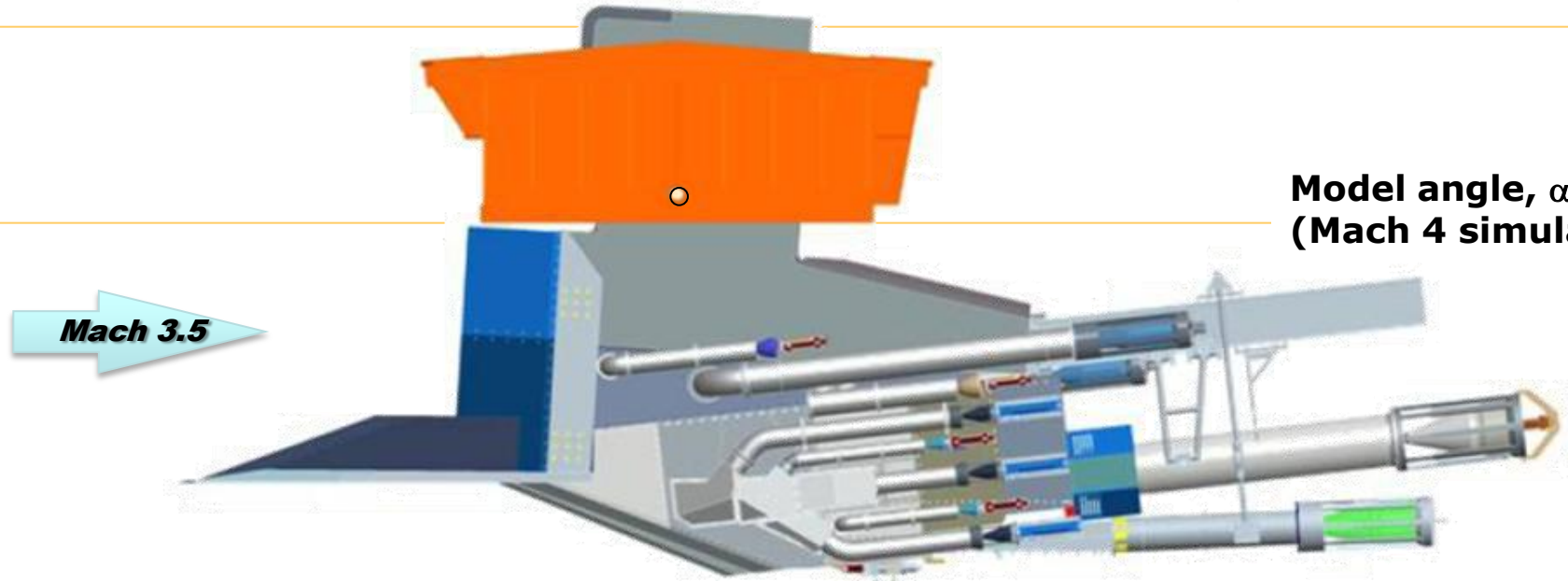
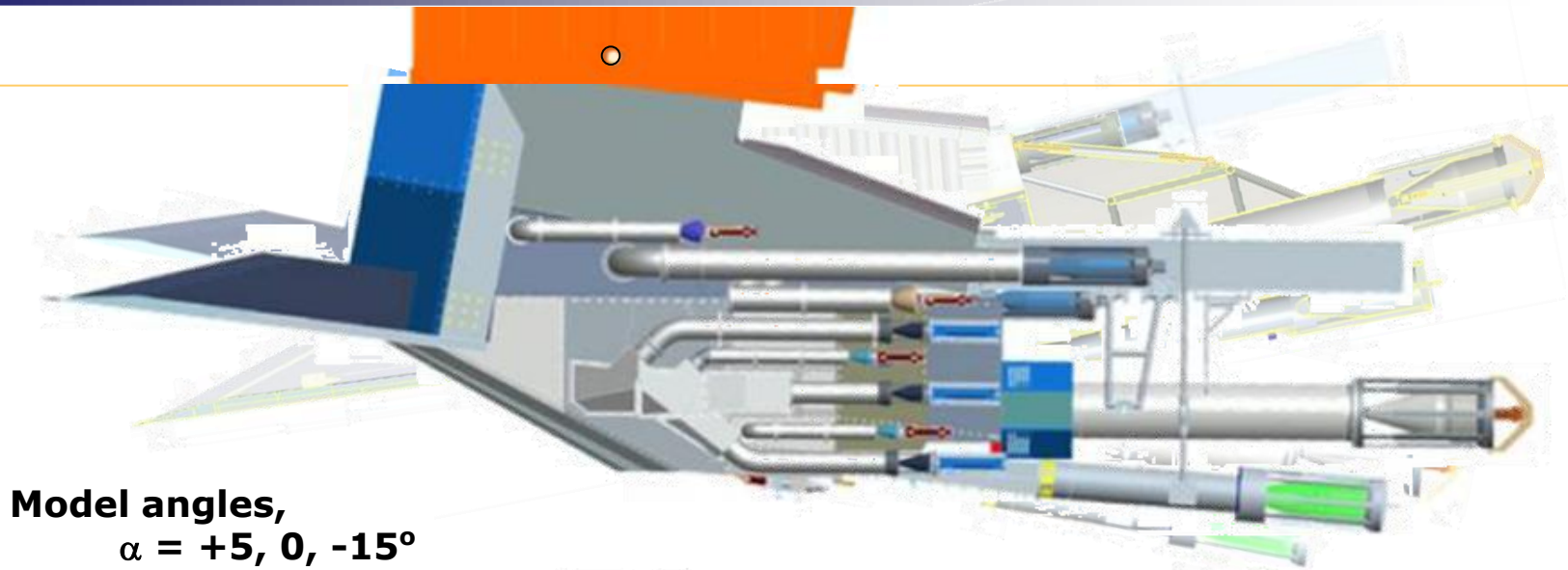
The ramp, low-speed cowl, and high-speed cowl can be rotated to change area distribution and capture flow rates.

Baseline Vortex Generator Configuration



The option exists to vary the number and orientation ($+16^\circ$ or -16°) of the vortex generators.

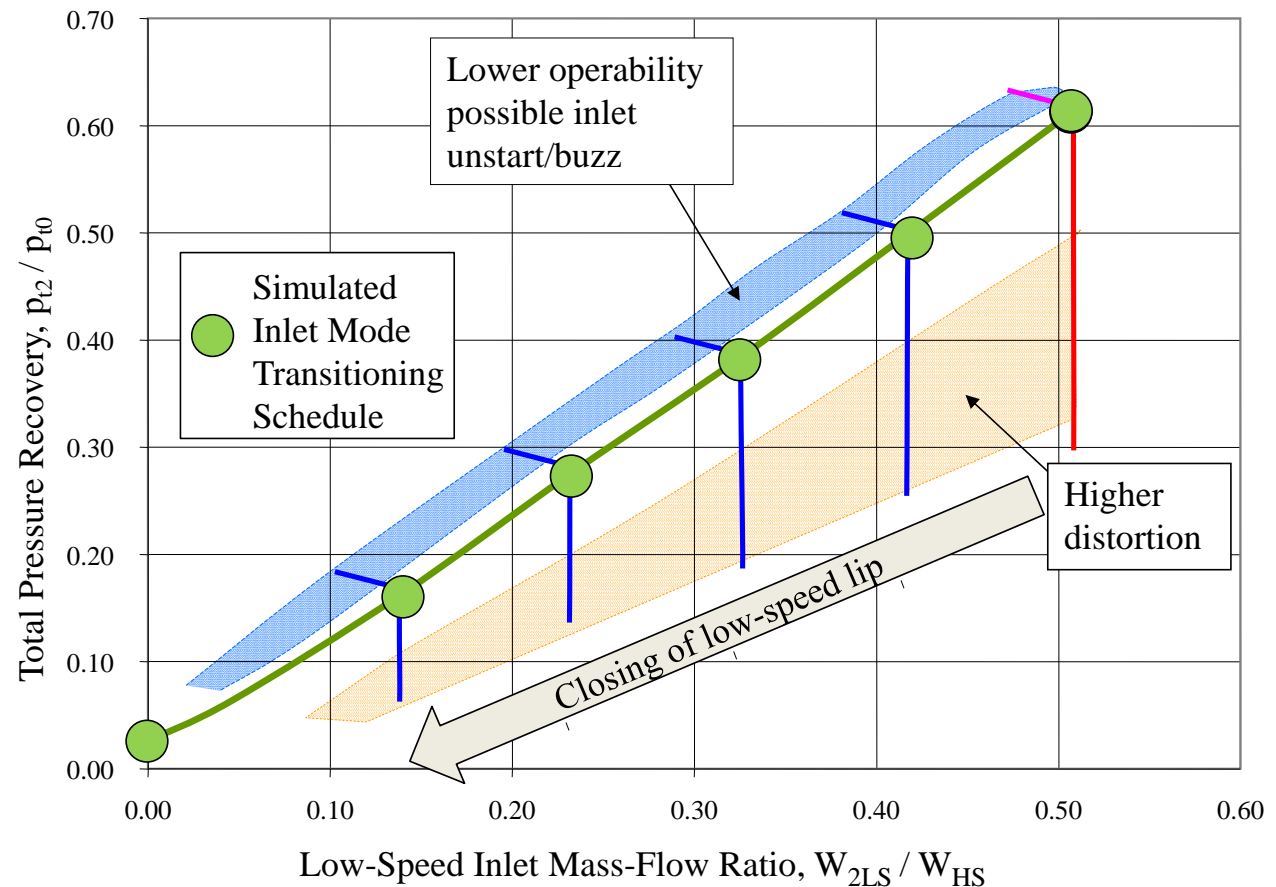
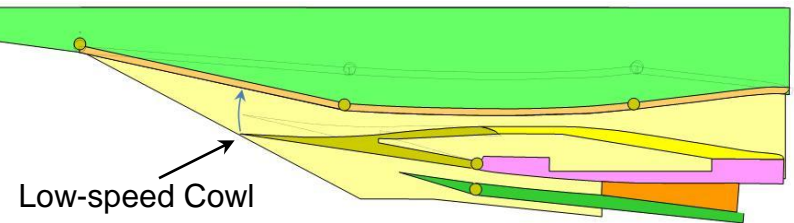
Range of Model Angle-of-Attack



Inlet Mode Transition Sequence



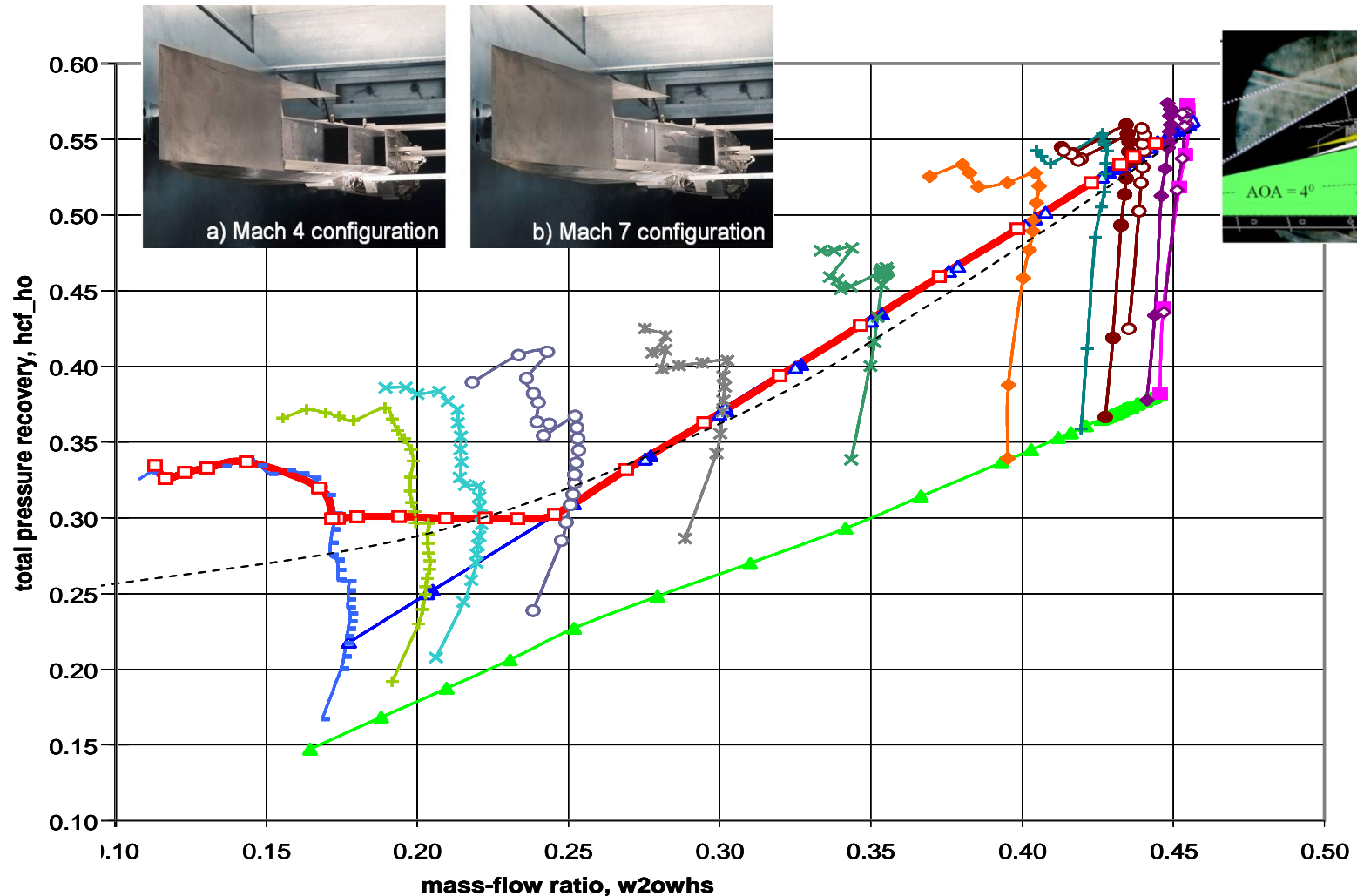
- **Primary Objective:** Demonstrate inlet mode transition at Mach 4.0 within about 5 seconds.
- Low-speed cowl rotates from open to closed.
- Maintain stable operation with high-performance in both flowpaths.
- Total pressure recovery goal is 65% (minimum of 57%).
- Cowl rotation signals other variable geometry elements to move:
 - ramp
 - high-speed cowl
 - mass flow plugs
- A secondary objective will be to demonstrate inlet mode transition at Mach 3.



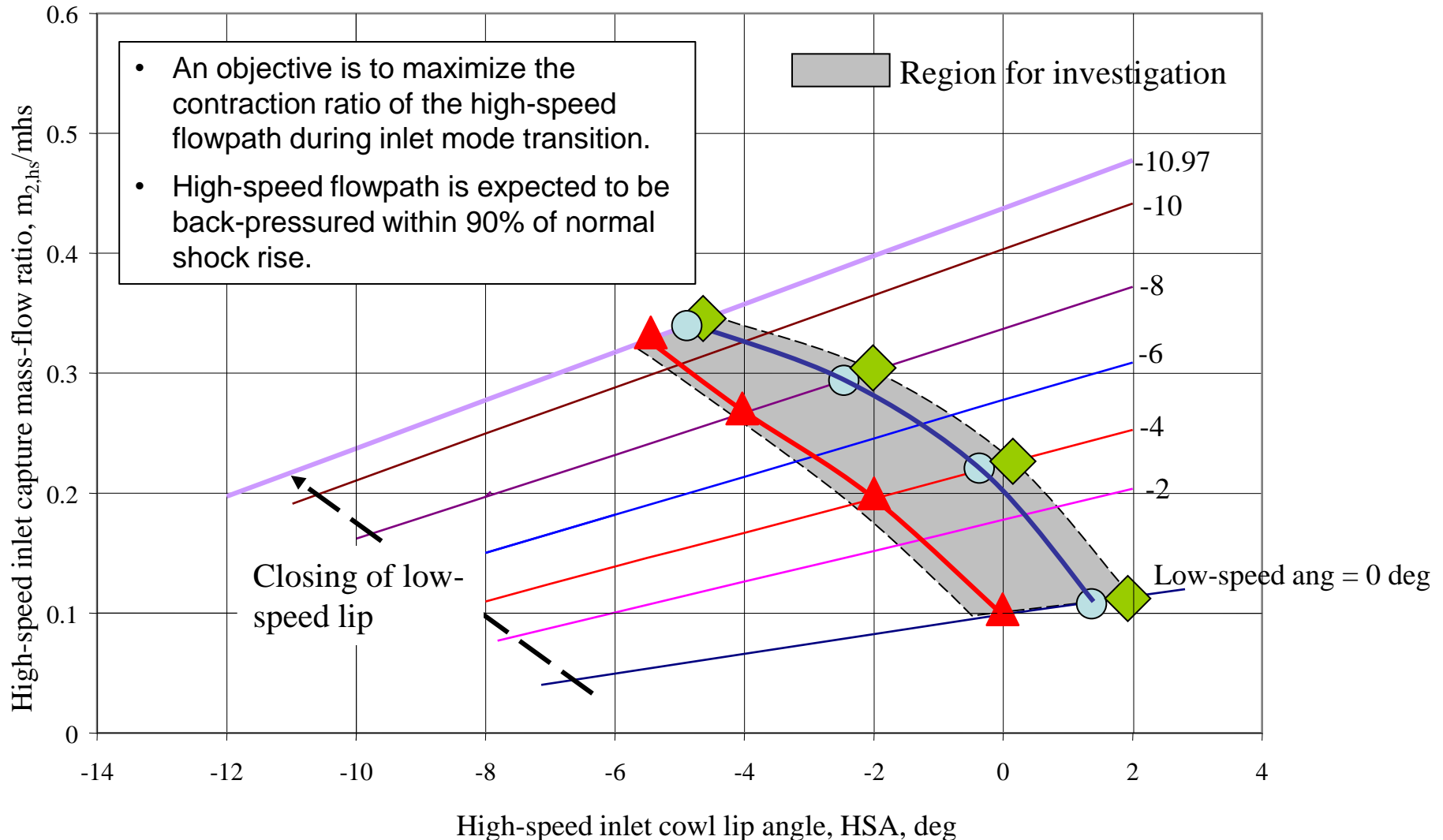
Inlet Mode Transition from IMX Test



NASA Glenn 1x1 ft Supersonic Wind Tunnel (2008)



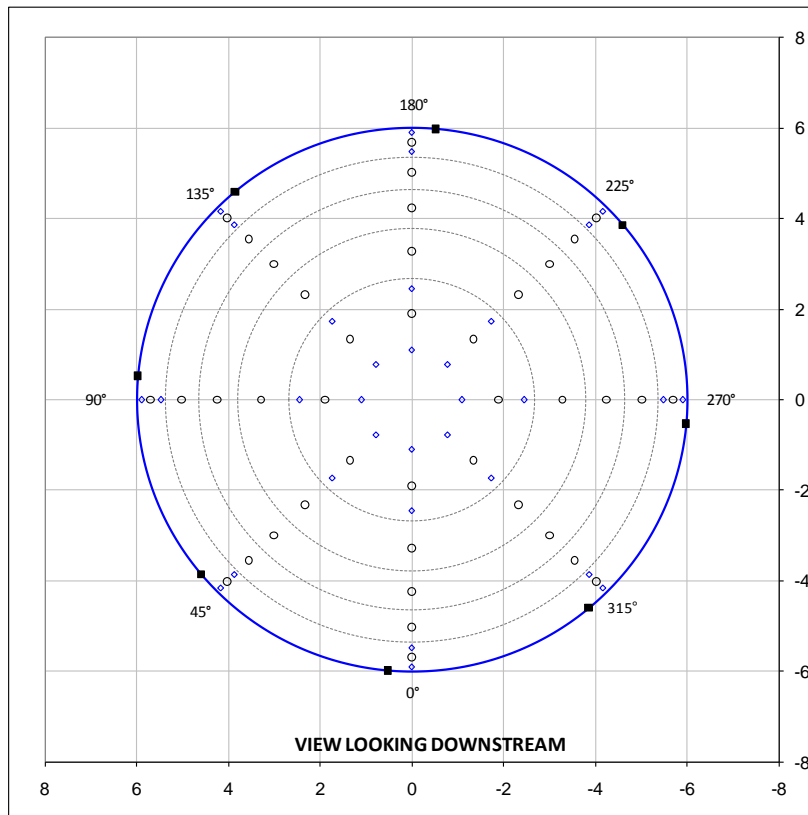
High-Speed Cowl Rotation Schedule



Engine-Face (AIP) Measurements



Objective: Assessment of steady-state and dynamic total pressure distortion at the turbine flowpath engine face (AIP) and high-speed isolator outflow.

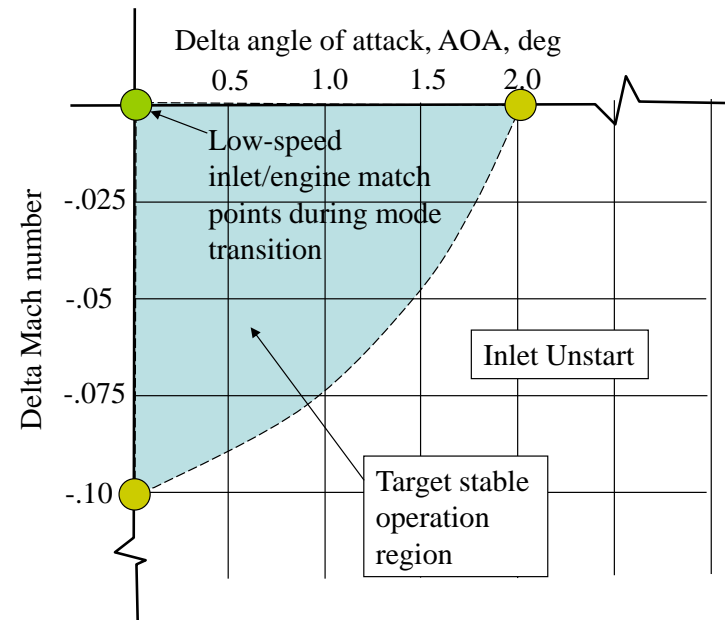


- 72-tube array of steady-state pressure measurements for turbine flowpath.
- 33-tube array in high-speed flowpath.
- Co-located dynamic pressure tubes.
- Area-averaged AIP calculations are made using 72-tube and standard 40-tube arrays.
 - Pitot pressure
 - Mach number
 - Corrected total pressure
 - Recovery
- Distortion:
 - (Max-Min)/Average
 - Williams International
 - ARP-1420
- Goals:
 - Distortion less than 10%
 - IMX tests indicated distortion < 10%

Off-Design and Operability



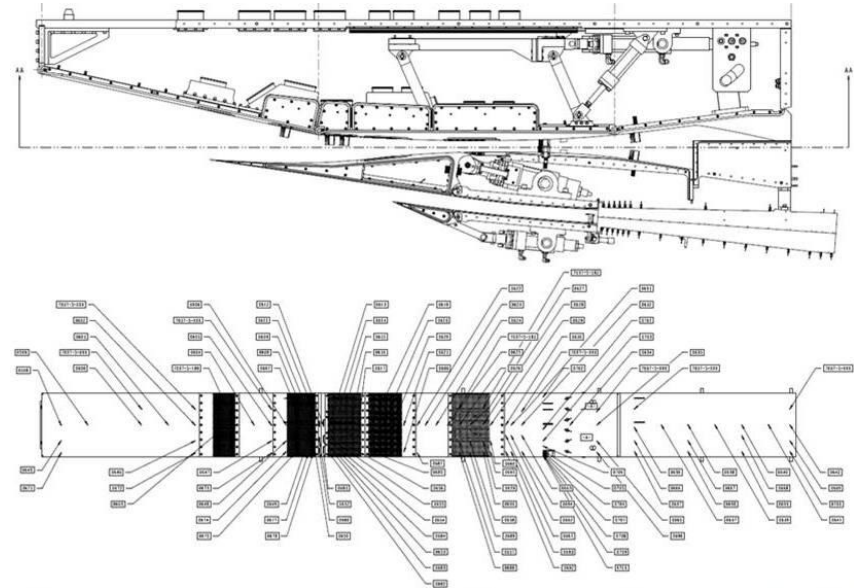
- Examine operation at Mach numbers between Mach 2.0 to 3.5.
- Explore change in performance as bleed rates and bleed patterns are varied.
- Maintain operation (avoid unstart in either flowpath) when subjected to:
 - ± 3 degrees angle-of-attack
 - -0.1 change in Mach number
- Goal is 10% stability index (change in corrected flow) .
- Examine inlet unstart recovery and restart.



Mapping the Inlet Flowfield



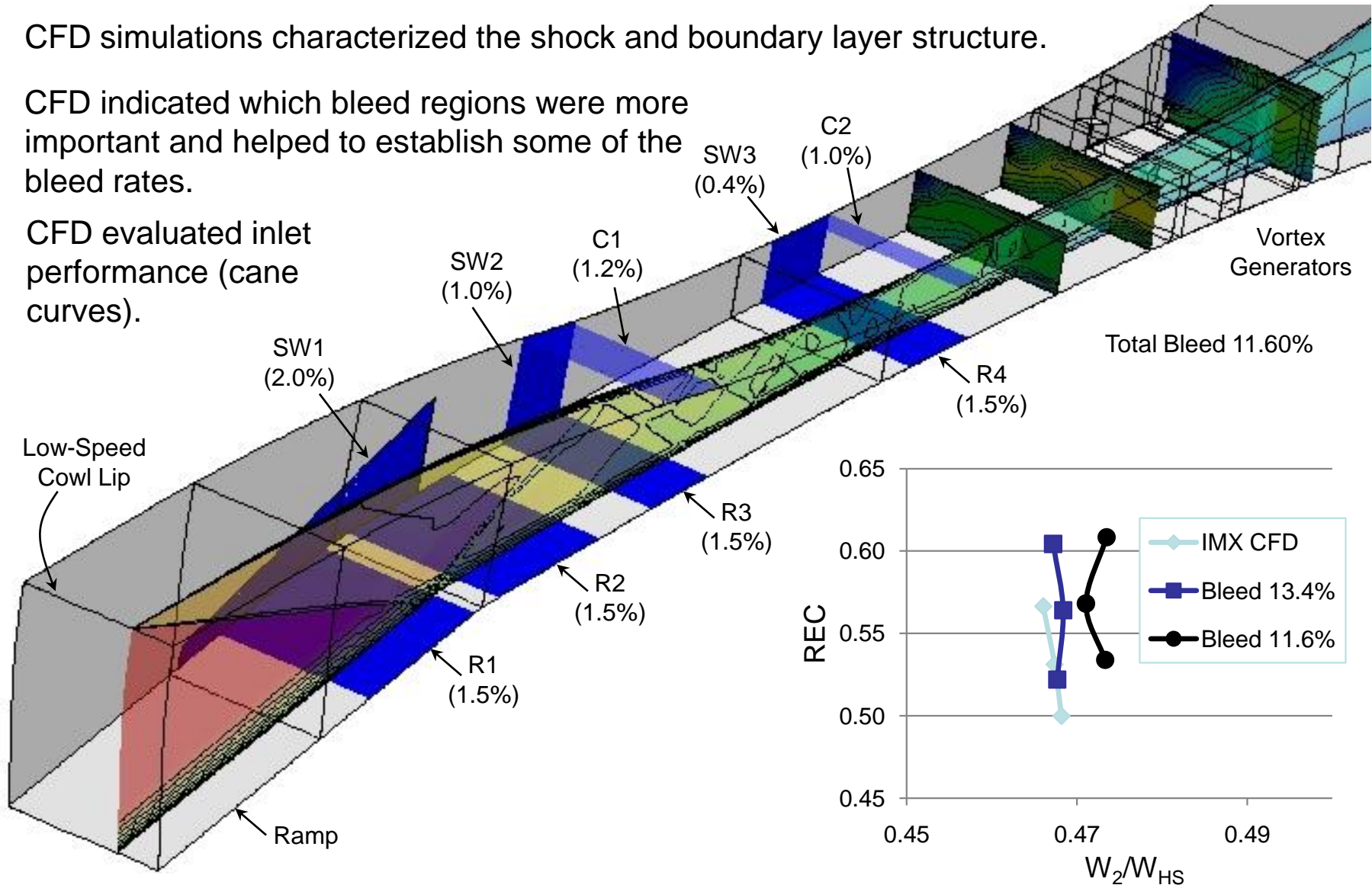
- **Objective:** Provide aerodynamic database of the flowfield.
- Data for CFD validation.
- Static pressure taps throughout model (800).
 - Turbine flowpath pressure distributions
 - Isolator performance
- Boundary layer rakes (total pressure profiles) at several ramp and cowl locations.
- Measure inlet and bleed flow rates through calibrated mass flow plugs.
- Schlieren is available, but only a small portion of the inlet is visible.



LIMX CFD: Low-Speed Flowpath



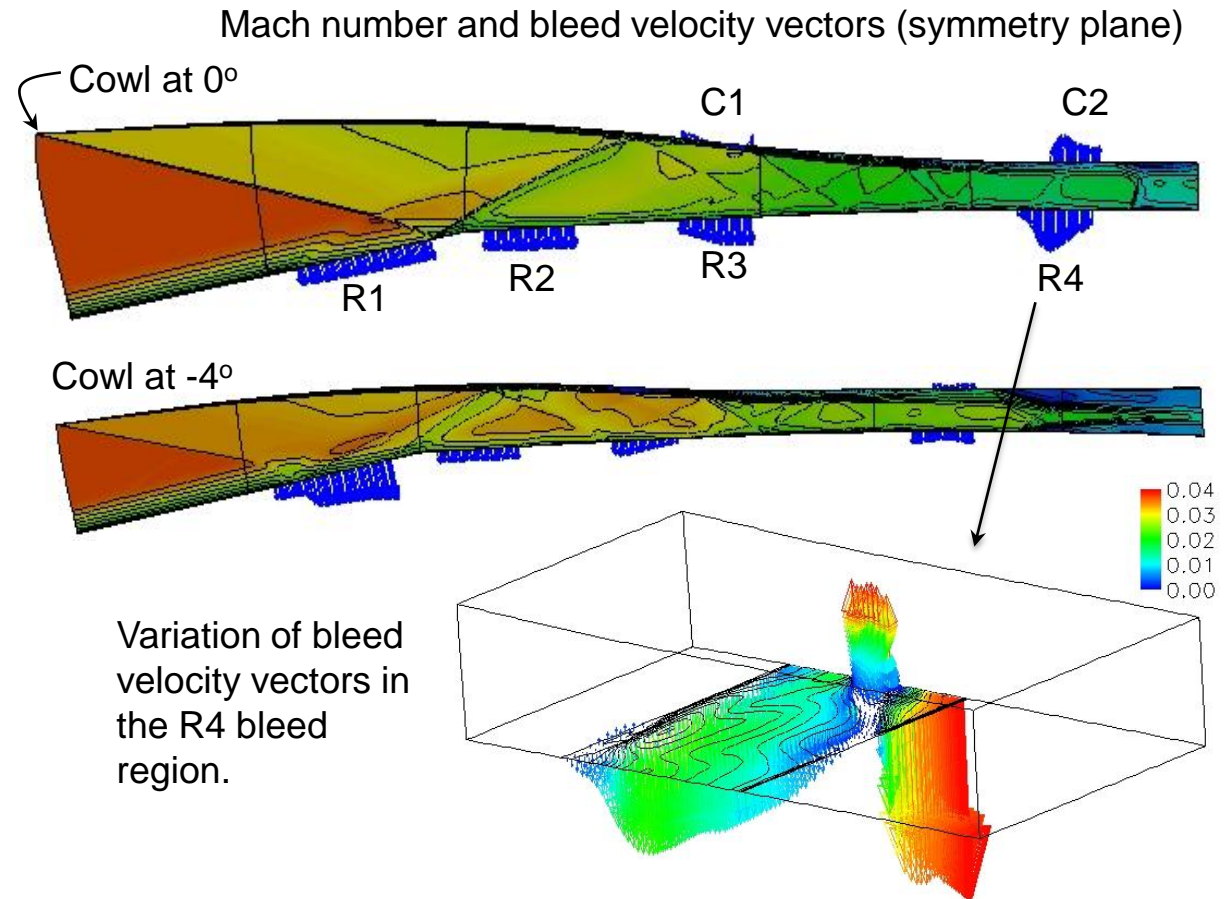
- CFD simulations characterized the shock and boundary layer structure.
- CFD indicated which bleed regions were more important and helped to establish some of the bleed rates.
- CFD evaluated inlet performance (cane curves).



LIMX CFD: Bleed Modeling



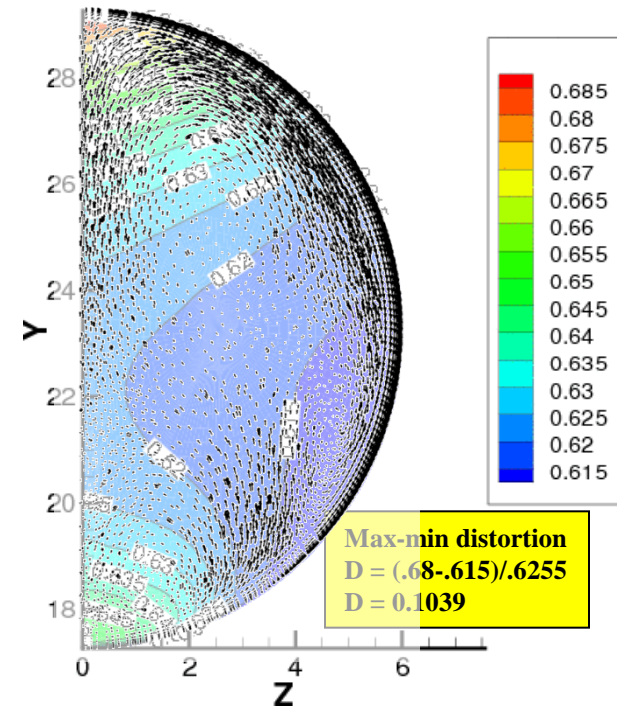
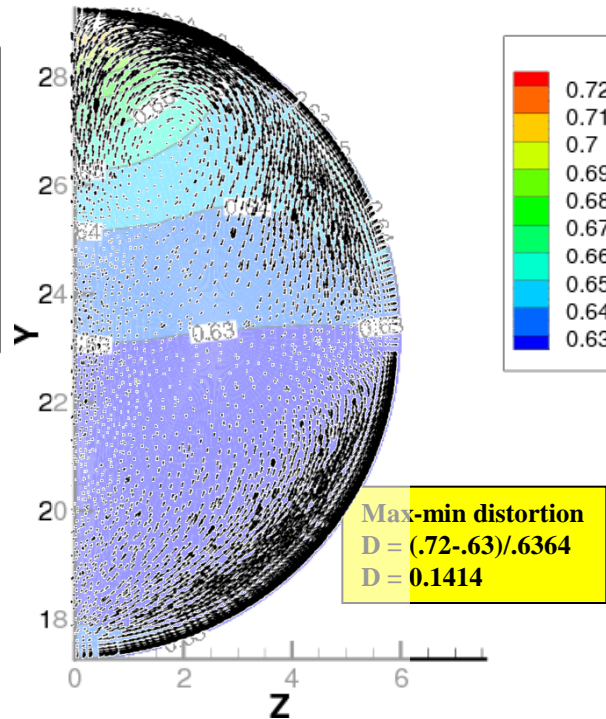
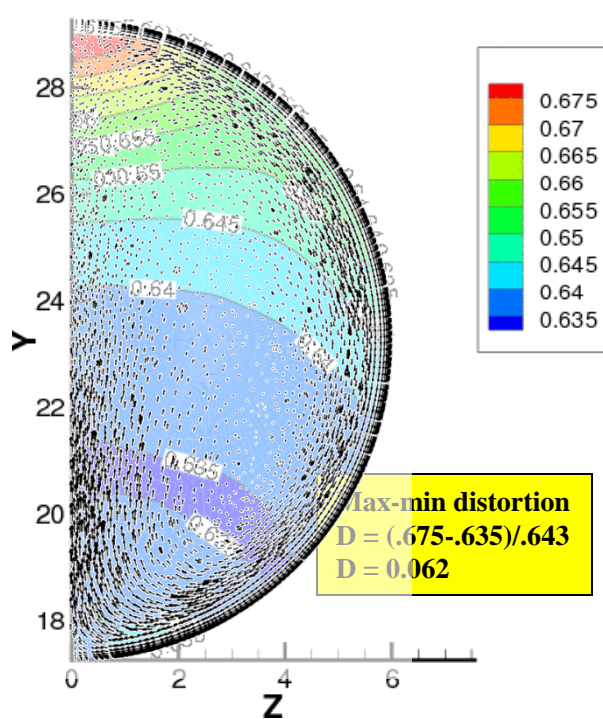
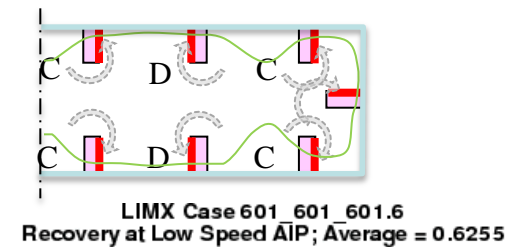
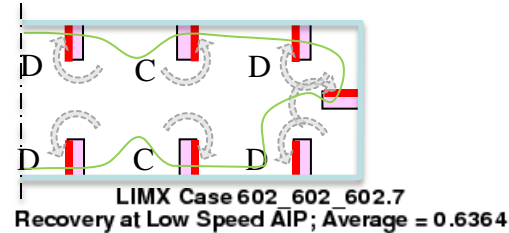
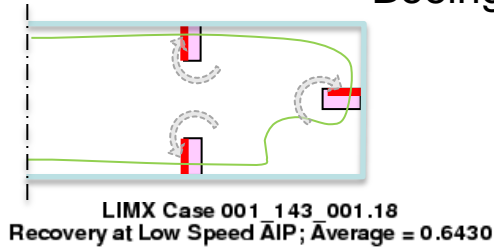
- Bleed rates may vary over the bleed region in response to shock waves within the flow field.
- Bleed model evaluates bleed rates and bleed plenum pressures based on local flow conditions and plenum exit conditions (fixed-area, choked exits).
- NASA bleed model was implemented into NPARC Wind-US and Boeing BCFD.



LIMX CFD: Vortex Generators



Boeing CFD



AIP flow field for Basic VG Configuration

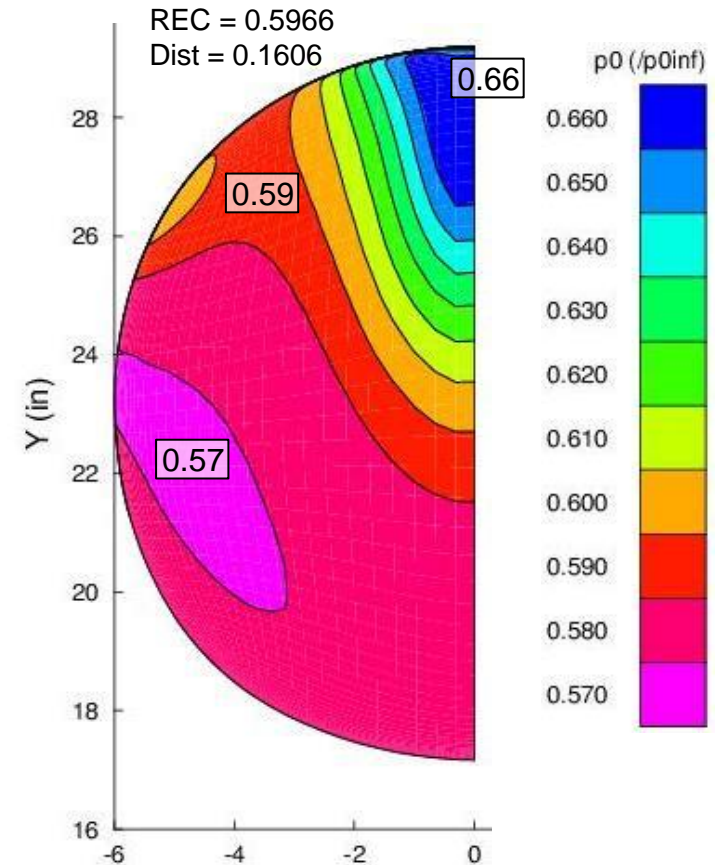
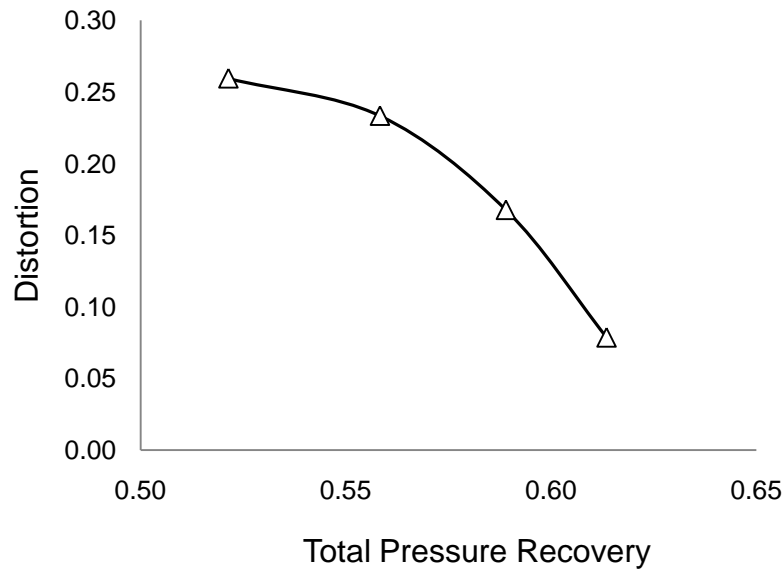
AIP flow field for the Alternate VG Configuration

AIP flow field for Alternate-Opposite VG Configuration

LIMX CFD: Distortion Estimation



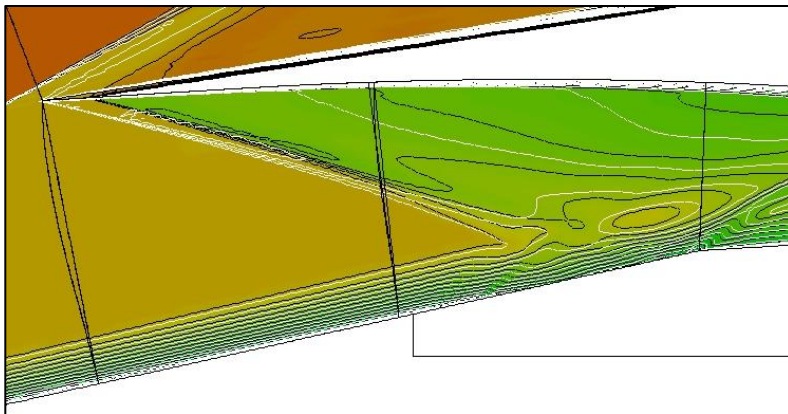
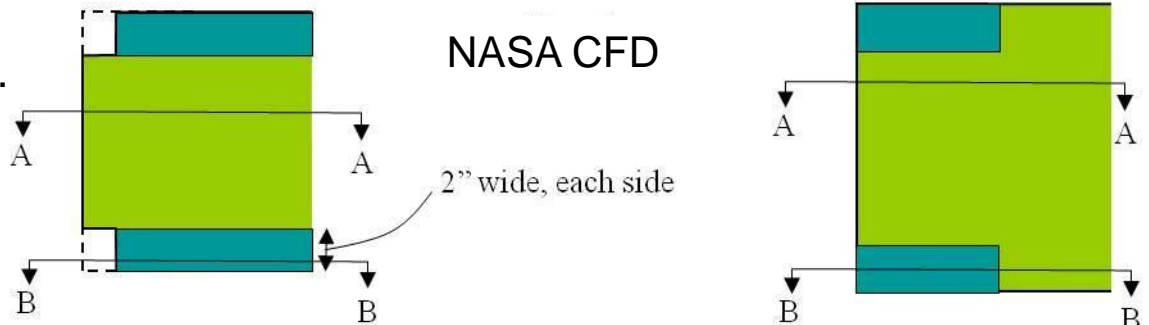
- CFD simulations were used to estimate total pressure distortion at the engine-face.
- Complex viscous flow in the subsonic diffuser as simulated by RANS solvers seemed to suggest a significant level of uncertainty.



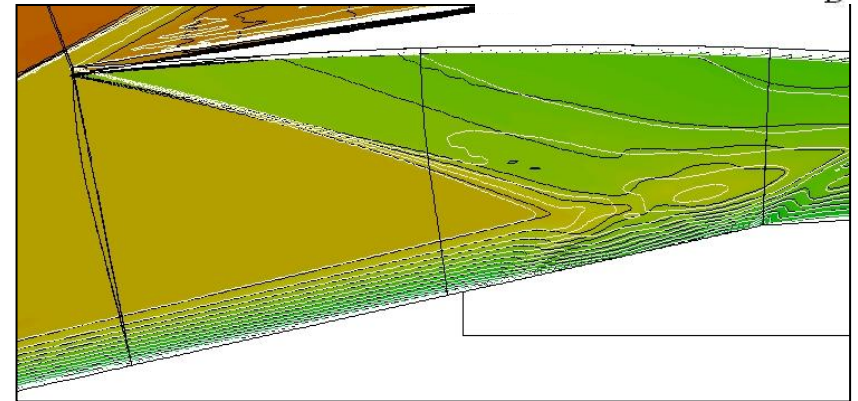
LIMX CFD: Low-Speed Cowl Modifications



- CFD simulations evaluated alternative cowl lips for the low-speed cowl.
- The objective was to reduce the shock / boundary layer interactions near the shoulder.
- Only a slight improvement in Mach contours and total pressure recovery was observed.

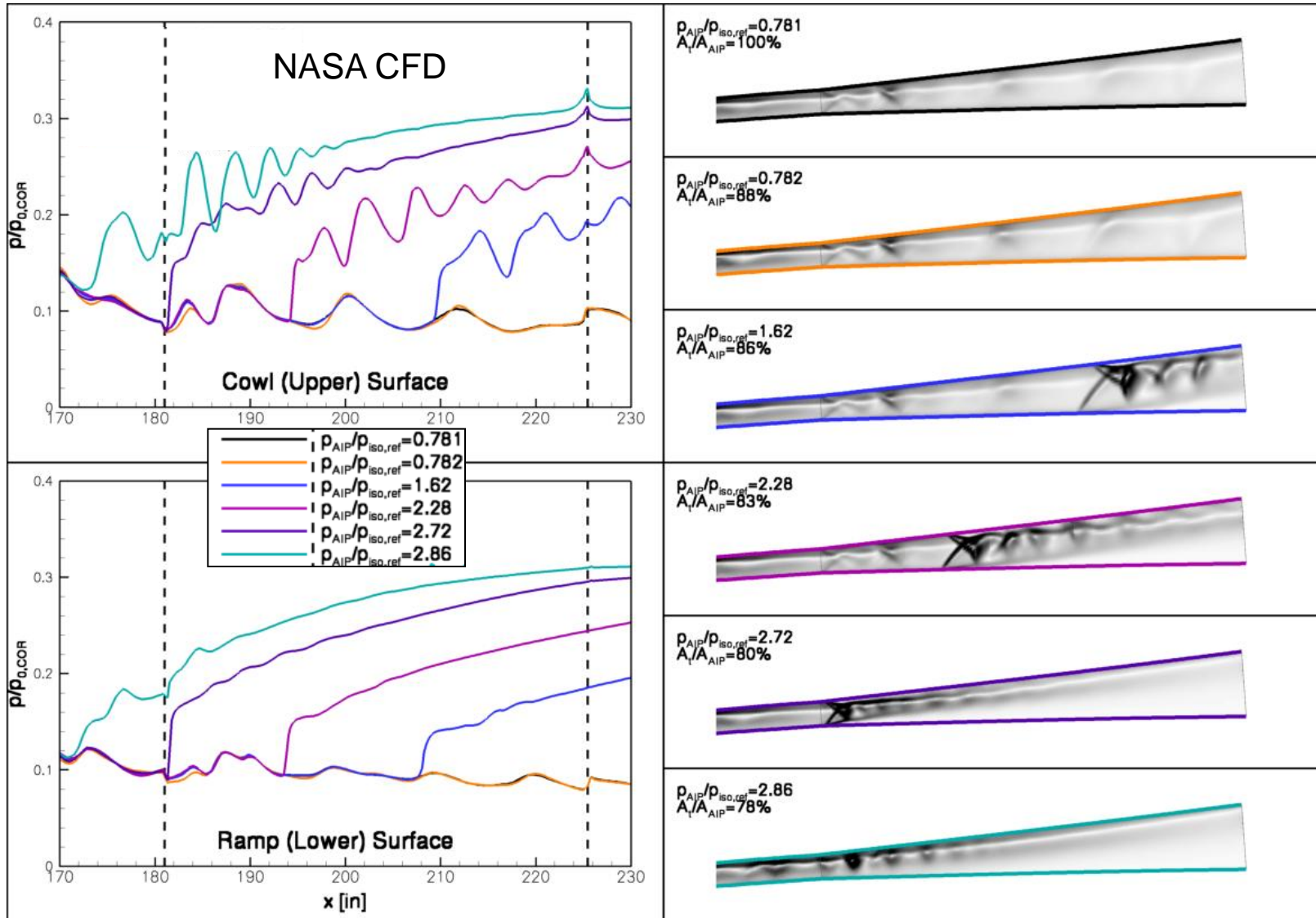


Cut-back cowl lip



2° Scoop Cowl Lip

LIMX CFD: High-Speed Flowpath



Dashed vertical lines denote isolator region

Summary / Status



- The LIMX experiment has been one of the most complicated inlet research models ever designed and fabricated for testing at GRC.
- Testing began on Monday, March 8th on 3rd shift.
- So far, runs have been focused on checking out the model operation and instrumentation under flow.
- The 10x10 SWT did experience a “hard unstart”, but the model held up well.
- Preliminary data are being collected and are encouraging.

